

EXHIBIT Y

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UNITED STATES DISTRICT COURT

NORTHERN DISTRICT OF CALIFORNIA

BEFORE THE HONORABLE JEFFREY S. WHITE

ALPHA and OMEGA SEMICONDUCTOR,)	
LTD., et al,)	
)	
Plaintiffs,)	
)	No. C 07-2638 JSW
VS.)	associated with
)	No. 07-2664 JSW
FAIRCHILD SEMICONDUCTOR)	
CORPORATION,,)	
)	San Francisco, California
Defendant.)	Wednesday
)	June 4, 2008
)	1:00 p.m.

TRANSCRIPT OF PROCEEDINGS

APPEARANCES:

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Reported By: Debra L. Pas, CSR 11916, CRR, RMR, RPR
Official Reporter - US District Court
Computerized Transcription By Eclipse

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1 **MR. JACOBS:** I'm looking for the cross section.

2 **THE COURT:** All right.

3 (Brief pause.)

4 **MR. JACOBS:** I believe that's in the termination
5 region.

6 **THE COURT:** All right. So those are my two
7 questions.

8 Now, would you like to comment on the Court's
9 proposal:

10 "Resulting in avalanche current that is
11 approximately evenly distributed across the entire
12 device"?

13 **MR. JACOBS:** We strongly believe that the claim
14 language itself states that the avalanche current is equally
15 distributed just across the active region, not the entire
16 device. That's the dispute between the parties.

17 **THE COURT:** All right. And your basis for that?

18 **MR. JACOBS:** Yes. Well, it's a very long claim, but
19 we have got a foam board, which is probably impossible for the
20 Court to read because the print is so small.

21 **THE COURT:** I can read the yellow. I could probably
22 read it.

23 **MR. JACOBS:** There is not one structure in Claim 9
24 (sic) which involves the termination region. Every structure
25 in Claim 29 is directed to the active area of the device, the

1 cells in the active area.

2 And it's clear that when describing the avalanche
3 current that's substantially uniformly distributed in this
4 claim, it's not referring to anything other than the active
5 area because no other structure is mentioned in the claim
6 itself.

7 **THE COURT:** So the big dispute point for you is
8 the -- the active region?

9 **MR. JACOBS:** Yes, your Honor.

10 **THE COURT:** Distribution over the active region?

11 **MR. JACOBS:** Even if Feature 40, as the Court just
12 described, is in the termination region, Feature 40 is not
13 mentioned anywhere in Claim 29.

14 **THE COURT:** Counsel?

15 **MR. SCHUMAN:** Well, we have a different problem with
16 a different portion of the Court's definition, but I will just
17 respond to Mr. Jacobs' point first.

18 Claim 29 is dealing with a trench transistor. A
19 trench transistor has an active region and a termination
20 region. And the intrinsic evidence that we cited -- I think
21 this is where the Court was focusing.

22 If you put up Slide 59, please?

23 (Document displayed)

24 This is the "draws" versus "thaws" quote. This is
25 the intrinsic evidence.

1 breakdown initiation point, it can be deemed infringing and
2 that's in conflict with the intrinsic evidence that I mentioned
3 and it would substantially broaden the claim scope.

4 **THE COURT:** Anything further on this point?

5 **MR. JACOBS:** Yes, your Honor. That exactly raises
6 the point, and that is we do not believe that an infringer gets
7 the ability to say, Gee, I just wanted an ohmic contact and by
8 accident, I'm also getting the benefit of the invention.
9 Therefore, I don't infringe. That's just not the way the law.

10 An ohmic contact, which is normally very shallow, can
11 be deep enough where it does impact where the breakdown occurs.
12 That's the '481 patent.

13 **THE COURT:** All right. Anything further?

14 **MR. SCHUMAN:** No, your Honor.

15 **THE COURT:** All right. We are going to take 10
16 minutes and then we will finish the rest of the terms. Thank
17 you counsel.

18 (Brief recess held in the proceedings.)

19 **THE COURT:** We are up to in the Fairchild '947
20 patent. This is '947 patent Claim 1:

21 "Acting as a field plate to extend the device
22 breakdown voltage in the breakdown region."

23 And the Court's proposal, which I want the parties to
24 address is as follows:

25 "Acting as a conductive structure, at least

1 much to what is in our briefs, but just to address one point
2 that's been raised.

3 There is nothing in this patent that says that the
4 contact 68 cannot act as a field plate. There is nothing. It
5 says that that item 64 does act as a field plate, but it never
6 says that item 68 cannot. So that's one point.

7 And another point is AOS's position is actually
8 contradicted by the claim language itself. If we go to -- here
9 we go.

10 (Document displayed)

11 If you look at the claim language of Claim 1 of the
12 '947 patent and we focus on the portion that's in red, we see
13 that the claim recites, "a single conductor having first and
14 second conductor portions."

15 And then it goes on to describe the second conductor
16 portion. The second conductor portion has three properties,
17 according to the claim. First, it includes a contact. Second,
18 it includes a feed. And, third, it acts as a field plate.

19 So this is just not the feed which is, I believe,
20 item 64 that was mentioned by opposing counsel. So it's not
21 just -- it's not just item 64 that's being referred to, but
22 it's the entire second conductor portion, including both the
23 contact and the feed.

24 And if that weren't the case, this claim would be
25 written differently.

1 background section of the patent describing prior art
2 techniques. They don't -- they are not cited at all for
3 describing the claimed invention.

4 And if we could put up our slide?

5 **THE COURT:** So you are saying the portion that
6 counsel just showed me is background?

7 **MR. LITTS:** Oh, yes, exactly. That's exactly where
8 it's cited, in the background connection of the patent to
9 describe prior art techniques.

10 **THE COURT:** Wait. Isn't that part of the intrinsic
11 evidence though?

12 **MR. LITTS:** Oh, sure. It's part of the intrinsic
13 evidence, but it's -- like I said, it's not cited for the
14 purpose of describing the invention. It's cited for the
15 purpose of describing prior art techniques. That's the reason
16 why it's there. And that's why it's in the background section
17 and it actually states that.

18 But also what's described in the Baliga text is
19 fundamentally different than the claimed invention. The Baliga
20 text describes a planar field plate that's on the surface of
21 the device, and the claimed invention is a trenched field
22 plate.

23 And the way this field plate operates is it's
24 fundamentally different than -- the way a field plate and a
25 trench operates is simply fundamentally different from the way

1 a planar field plate operates. And you can see the regions
2 that we are concerned with (indicating).

3 In the Baliga text we are concerned with this rounded
4 region where the P⁺ body and the epitaxial layer meet.

5 And in the '947 patent we are concerned with this
6 area that's circled here, that's alongside the trenched field
7 plate.

8 So these are just fundamentally different structures,
9 fundamentally different types of field plates.

10 Furthermore, what AOS is trying to do is impose a
11 cause-and-effect requirement. So they are saying that not only
12 does a field plate affect depletion layers and not only does it
13 increase breakdown voltage, but the breakdown voltage increase
14 is caused by modification of the depletion layers.

15 Now, this cause-and-effect relationship isn't imposed
16 anywhere. There are numerous factors that can effect breakdown
17 voltage. We heard a number of them during the tutorials.

18 We heard about lines of equal potential. We heard
19 about electric fields. We also heard about depletion regions.
20 But it's improper to select any one of these and say this is
21 the cause of the breakdown voltage that results from using a
22 field plate. There is no support for that.

23 **THE COURT:** Anything further?

24 **MR. WU:** Well, just briefly. I think what we are
25 hearing again is Fairchild relying on Dr. Blanchard when they

CERTIFICATE OF REPORTER

I, DEBRA L. PAS, Official Reporter for the United States Court, Northern District of California, hereby certify that the foregoing proceedings in C 07-2638 JSW, ALPHA and OMEGA SEMICONDUCTOR, LTD. versus FAIRCHILD SEMICONDUCTOR CORPORATION were reported by me, a certified shorthand reporter, and were thereafter transcribed under my direction into typewriting; that the foregoing is a full, complete and true record of said proceedings as bound by me at the time of filing.

The validity of the reporter's certification of said transcript may be void upon disassembly and/or removal from the court file.

Debra L. Pas, CSR 11916, CRR, RMR, RPR

Monday, June 23, 2008

Debra L. Pas, CSR, CRR, RMR, RPR
Official Reporter - U.S. District Court - San Francisco, California
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EXHIBIT Z



US006828195B2

(12) **United States Patent**
Mo et al.

(10) **Patent No.:** **US 6,828,195 B2**
(45) **Date of Patent:** **Dec. 7, 2004**

(54) **METHOD OF MANUFACTURING A TRENCH TRANSISTOR HAVING A HEAVY BODY REGION**

(75) Inventors: **Brian Sze-Ki Mo**, Fremont, CA (US); **Duc Chau**, San Jose, CA (US); **Steven Sapp**, Felton, CA (US); **Izak Bencuya**, Saratoga, CA (US); **Dean Edward Probst**, West Jordan, UT (US)

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(73) Assignee: **Fairchild Semiconductor Corporation**, South Portland, ME (US)

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(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 0 days.

(List continued on next page.)

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(21) Appl. No.: **10/347,254**

(22) Filed: **Jan. 17, 2003**

(65) **Prior Publication Data**

US 2003/0127688 A1 Jul. 10, 2003

Related U.S. Application Data

(60) Continuation of application No. 09/854,102, filed on May 9, 2001, now Pat. No. 6,521,497, which is a division of application No. 08/970,221, filed on Nov. 14, 1997, now Pat. No. 6,429,481.

(51) **Int. Cl.**⁷ **H01L 21/336**

(52) **U.S. Cl.** **438/270; 438/589**

(58) **Field of Search** **438/270-272, 438/589**

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Primary Examiner—John F. Niebling

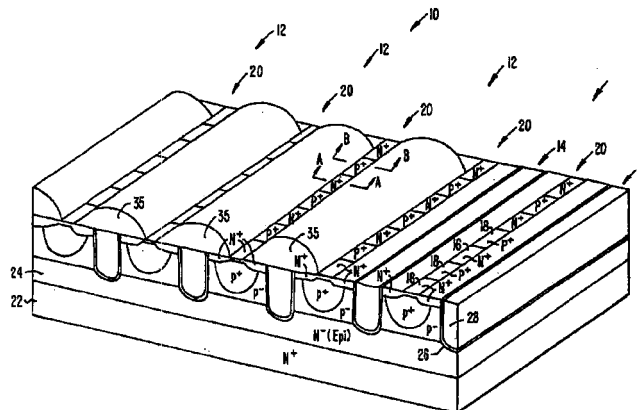
Assistant Examiner—Angel Roman

(74) *Attorney, Agent, or Firm*—Babak S. Sani; Townsend and Townsend and Crew LLP

(57) **ABSTRACT**

A trench field effect transistor is provided that includes (a) a semiconductor substrate, (b) a trench extending a predetermined depth into the semiconductor substrate, (c) a pair of doped source junctions, positioned on opposite sides of the trench, (d) a doped heavy body positioned adjacent each source junction on the opposite side of the source junction from the trench, the deepest portion of the heavy body extending less deeply into said semiconductor substrate than the predetermined depth of the trench, and (e) a doped well surrounding the heavy body beneath the heavy body.

23 Claims, 9 Drawing Sheets



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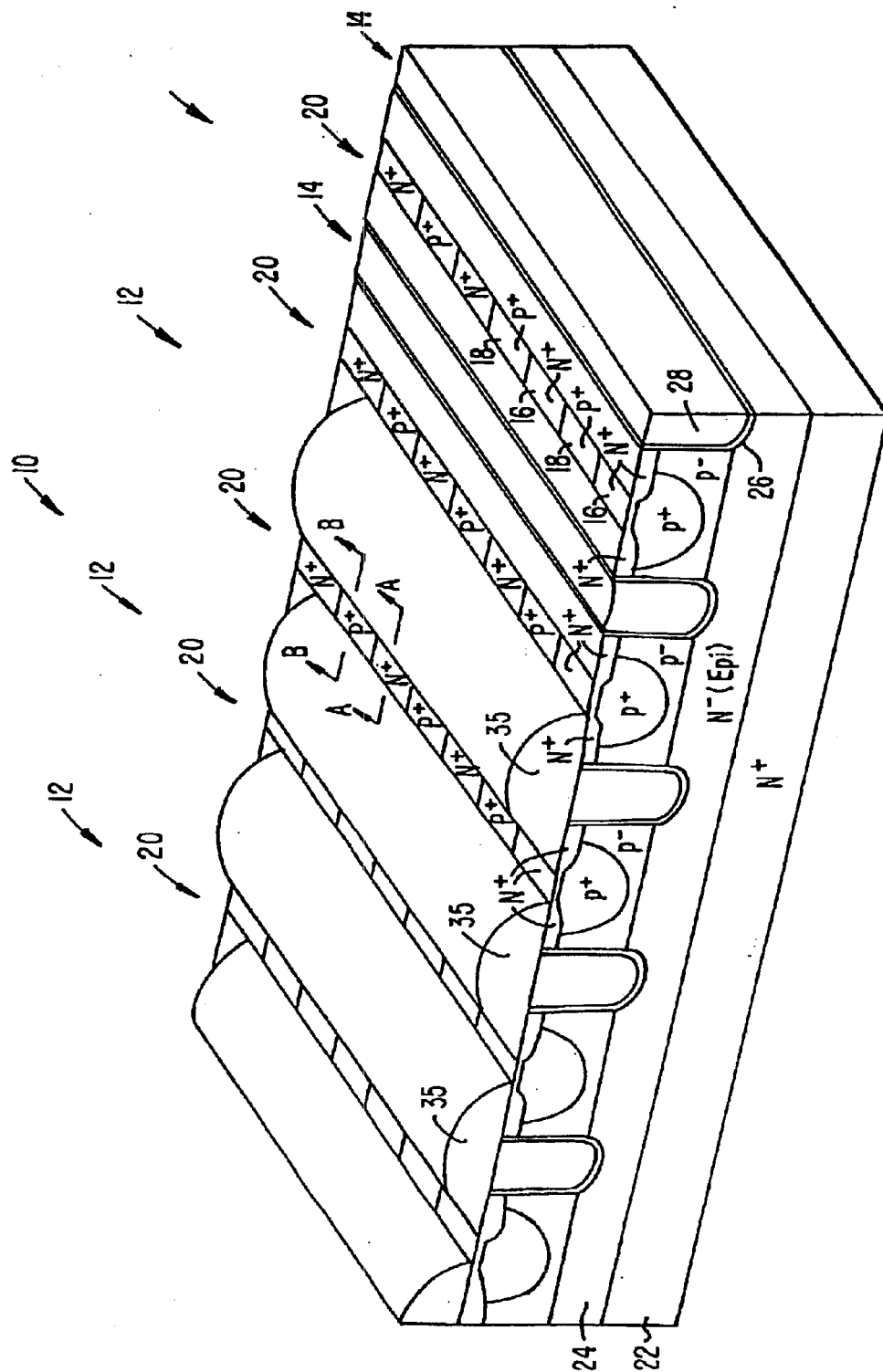


FIG. 1.

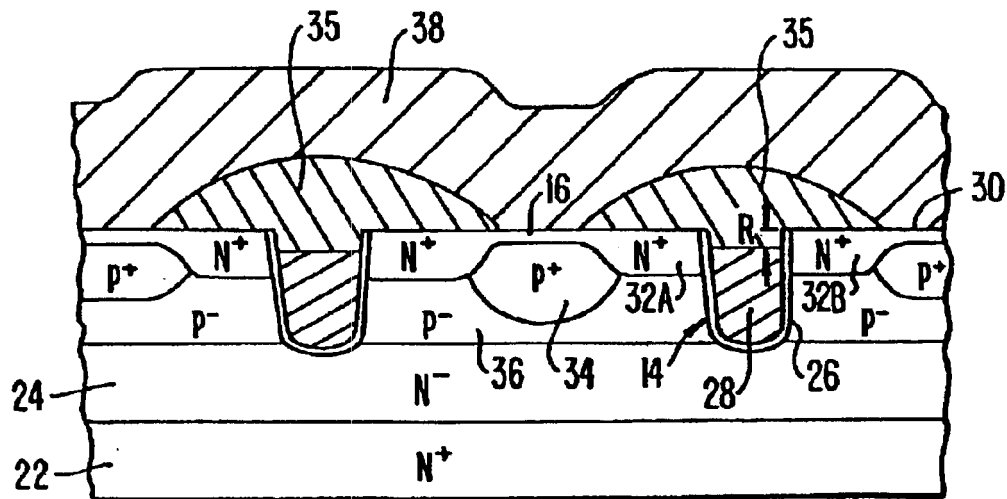


FIG. 1A.

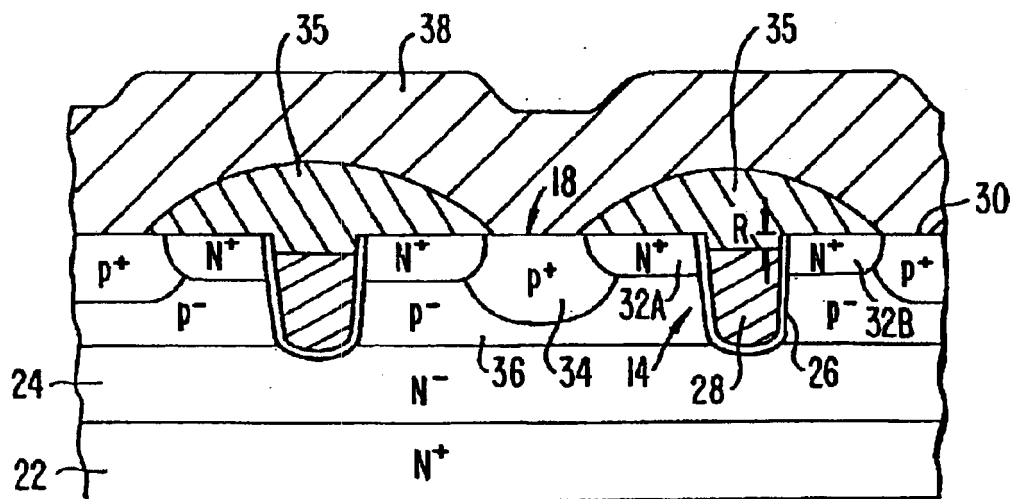


FIG. 1B.

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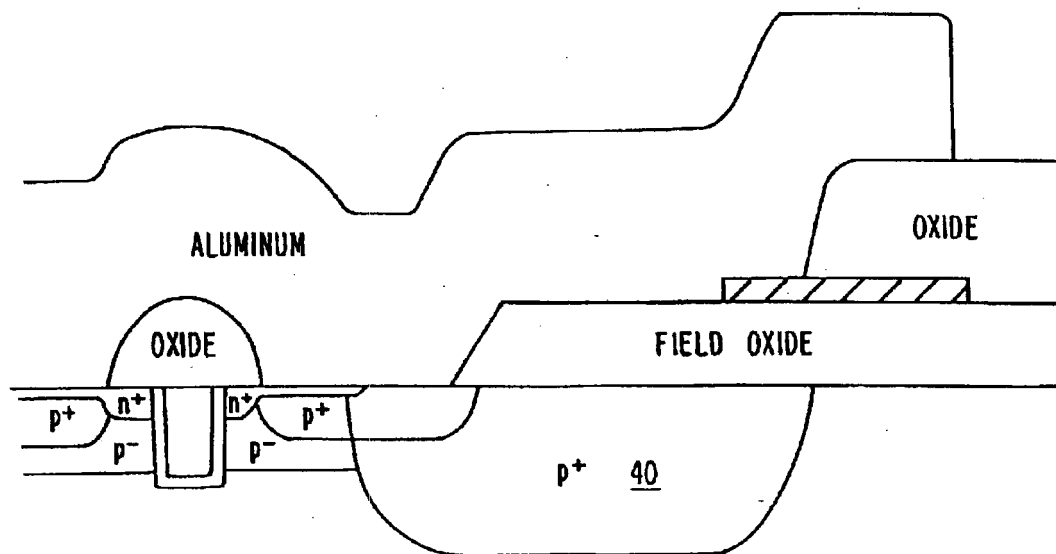


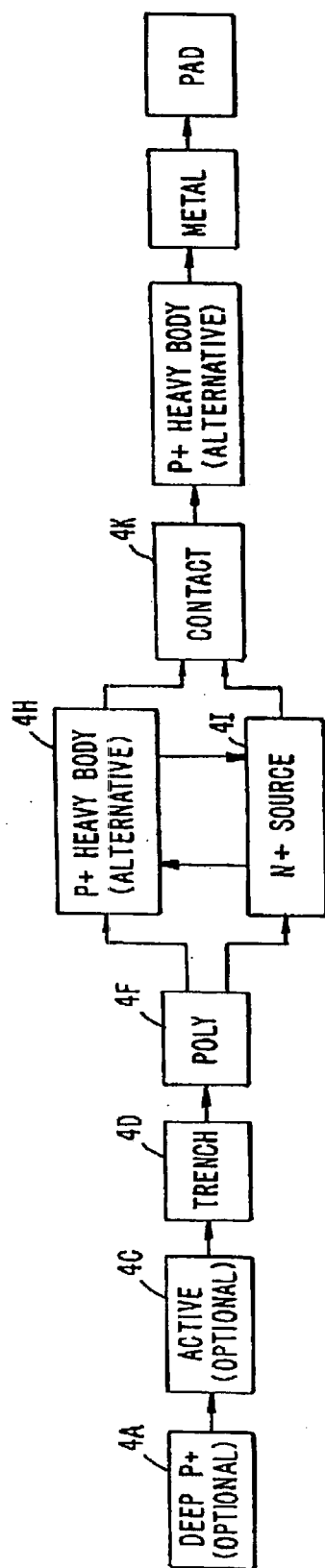
FIG. 2.

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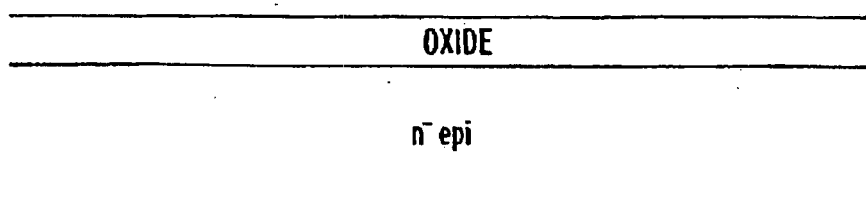


FIG. 4.

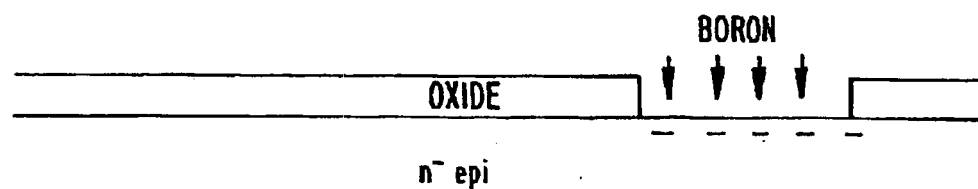


FIG. 4A.

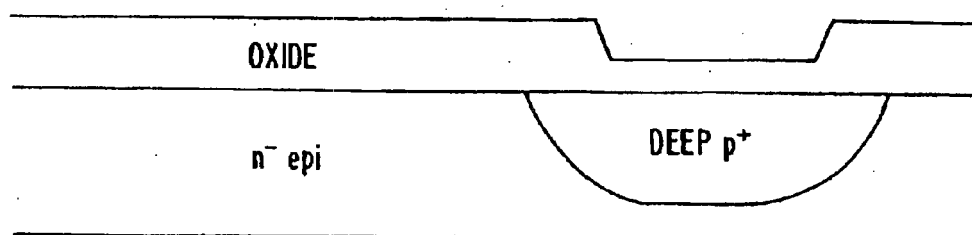


FIG. 4B.

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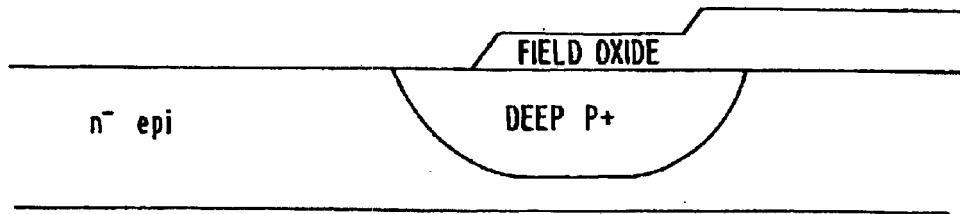


FIG. 4C.

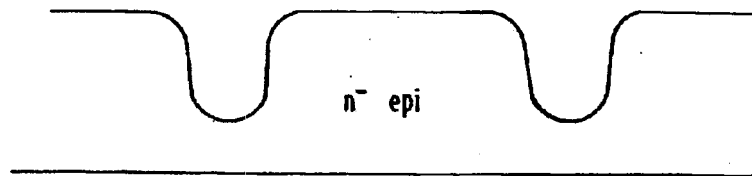


FIG. 4D.

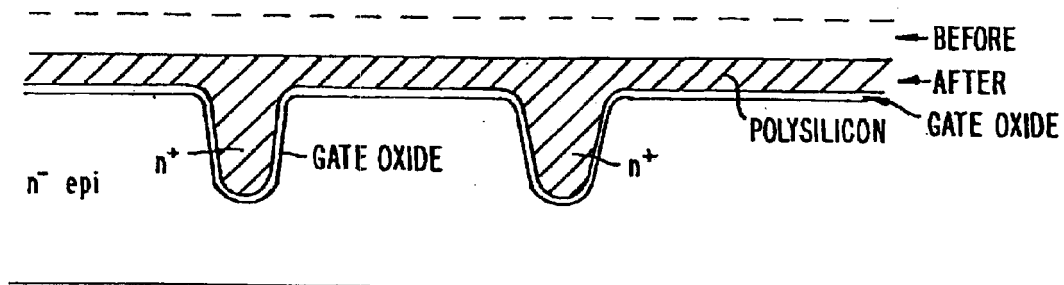


FIG. 4E.

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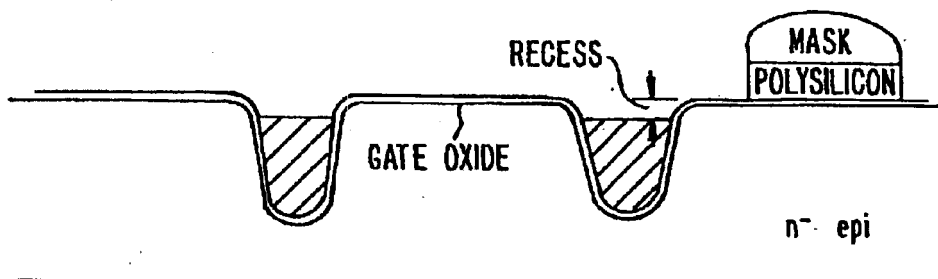


FIG. 4F.

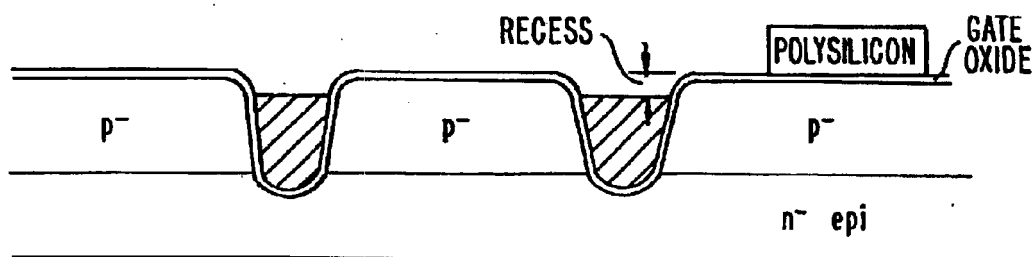


FIG. 4G.

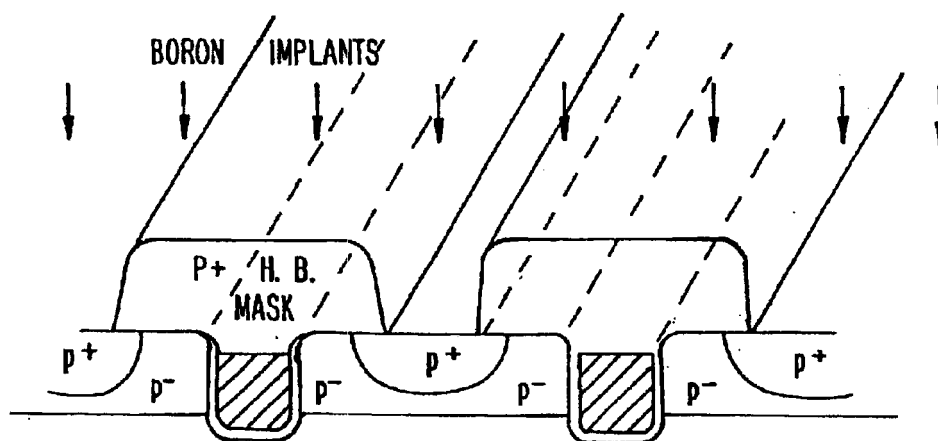


FIG. 4H.

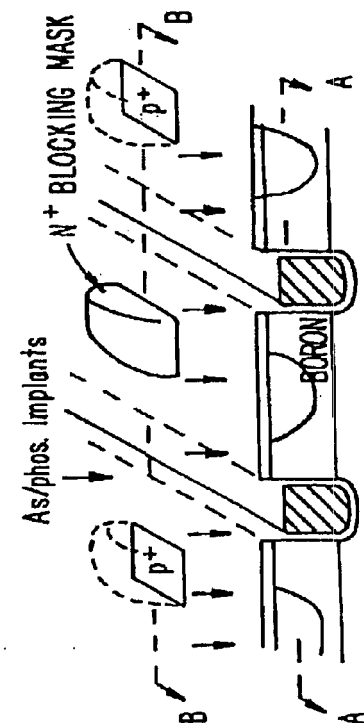


FIG. 4I.

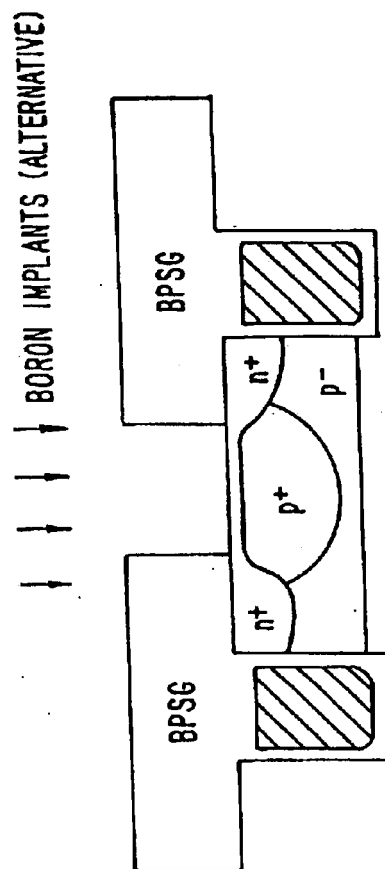


FIG. 4J.

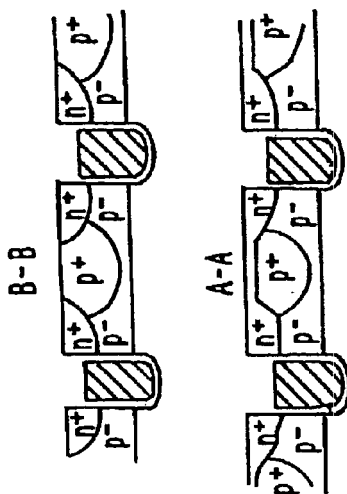


FIG. 4K.

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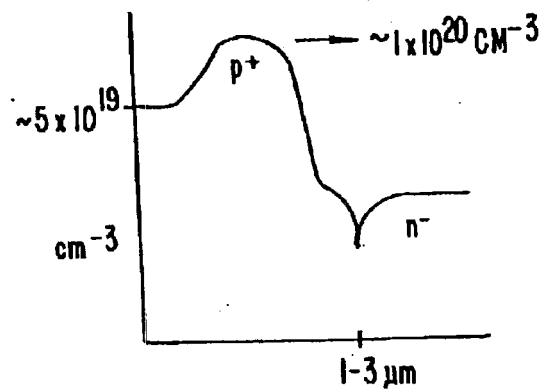


FIG. 5.

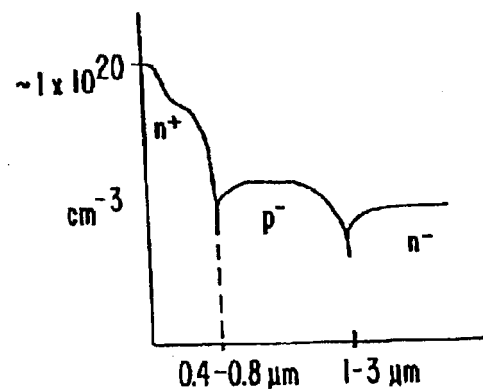


FIG. 5A.

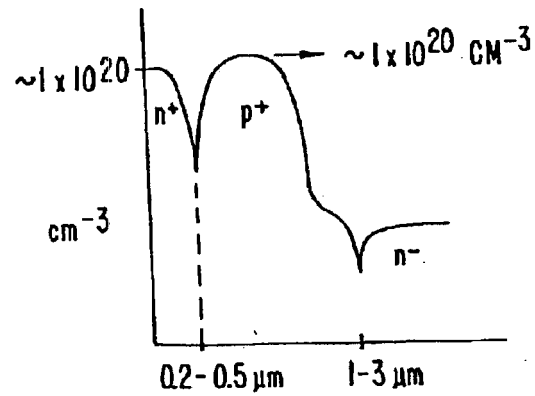


FIG. 5B.

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1

METHOD OF MANUFACTURING A TRENCH TRANSISTOR HAVING A HEAVY BODY REGION

This application is a continuation of and claims the benefit of U.S. application Ser. No. 09/854,102 filed May 9, 2001, now U.S. Pat. No. 6,521,497, which is a divisional of U.S. application Ser. No. 08/970,221 filed Nov. 14, 1997.

BACKGROUND OF THE INVENTION

The present invention relates to field effect transistors, in particular trench DMOS transistors, and methods of their manufacture.

Power field effect transistors, e.g., MOSFETs (metal oxide semiconductor field effect transistors), are well known in the semiconductor industry. One type of MOSFET is a DMOS (double diffused metal oxide semiconductor) transistor. DMOS transistors typically include a substrate on which an epitaxial layer is grown, a doped source junction, a doped heavy body, a doped well of the same (p or n) doping as the heavy body, and a gate electrode. In trench DMOS transistors the gate electrode is a vertical trench. The heavy body is typically diffused deeper than the bottom of the trench, to minimize electric field at the bottom corners of the trench and thereby prevent avalanche breakdown from damaging the device. The trench is filled with conductive polysilicon, and the polysilicon is generally overetched, to assure that it is completely removed from the surface surrounding the trench. This overetching generally leaves a recess between the top of the polysilicon and the surface of the semiconductor substrate (i.e., the surface of the epitaxial layer). The depth of this recess must be carefully controlled so that it is shallower than the depth of the source junctions. If the recess is deeper than the source junctions the source may miss the gate, resulting in high on-state resistance, high threshold, and potentially a non-functional transistor.

The source and drain junctions can be doped with either p-type or n-type dopants; in either case, the body will be doped with the opposite dopant, e.g., for n-type source and drain the body will be p-type. DMOS transistors in which the source and drain are doped with p-type carriers are referred to as "p-channel". In p-channel DMOS transistors a negative voltage applied to the transistor gate causes current flow from the source region, through a channel region of the body, an accumulation region of the epitaxial layer, and the substrate, to the drain region. Conversely, DMOS transistors, in which the source and drain are doped with n-type carriers, are referred to as "n-channel". In n-channel DMOS transistors a positive voltage applied to the transistor gate causes current to flow from drain to source.

It is desirable that DMOS transistors have low source to drain resistance ($R_{ds(on)}$) when turned on and low parasitic capacitance. The transistor structure should also avoid "punchthrough". Punchthrough occurs when, upon application of a high drain to source voltage, depletion into the body region extends to the source region, forming an undesirable conductive path through the body region when the transistor should be off. Finally, the transistor should have good "ruggedness", i.e., a high activation current is needed to turn on the parasitic transistor that inherently exists in DMOS transistors.

Generally a large number of MOSFET cells are connected in parallel forming a single transistor. The cells may be arranged in a "closed cell" configuration, in which the trenches are laid out in a grid pattern and the cells are enclosed on all sides by trench walls. Alternatively, the cells

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may be arranged in an "open cell" configuration, in which the trenches are laid out in a "stripe" pattern and the cells are only enclosed on two sides by trench walls. Electric field termination techniques are used to terminate junctions (doped regions) at the periphery (edges) of the silicon die on which the transistors are formed. This tends to cause the breakdown voltage to be higher than it would otherwise be if controlled only by the features of the active transistor cells in the central portions of the die.

SUMMARY OF THE INVENTION

The present invention provides field effect transistors that have an open cell layout that provides good uniformity and high cell density and that is readily scalable. Preferred trench DMOS transistors exhibit low $R_{ds(on)}$, low parasitic capacitance, excellent reliability, resistance to avalanche breakdown degradation, and ruggedness. Preferred devices also include a field termination that enhances resistance to avalanche breakdown. The invention also features a method of making trench DMOS transistors.

In one aspect, the invention features a trench field effect transistor that includes

(a) a semiconductor substrate, (b) a trench extending a predetermined depth into the semiconductor substrate, (c) a pair of doped source junctions, positioned on opposite sides of the trench, (d) a doped heavy body positioned adjacent each source junction on the opposite side of the source junction from the trench, the deepest portion of the heavy body extending less deeply into said semiconductor substrate than the predetermined depth of the trench, and (e) a doped well surrounding the heavy body beneath the heavy body.

Preferred embodiments include one or more of the following features. The doped well has a substantially flat bottom. The depth of the heavy body region relative to the depths of the well and the trench is selected so that the peak electric field, when voltage is applied to the transistor, will be spaced from the trench. The doped well has a depth less than the predetermined depth of the trench. The trench has rounded top and bottom corners. There is an abrupt junction at the interface between the heavy body and the well, to cause the peak electric field, when voltage is applied to the transistor, to occur in the area of the interface.

In another aspect, the invention features an array of transistor cells. The array includes (a) a semiconductor substrate, (b) a plurality of gate-forming trenches arranged substantially parallel to each other and extending in a first direction, the space between adjacent trenches defining a contact area, each trench extending a predetermined depth into said substrate, the predetermined depth being substantially the same for all of said gate-forming trenches; (c) surrounding each trench, a pair of doped source junctions, positioned on opposite sides of the trench and extending along the length of the trench, (d) positioned between each pair of gate-forming trenches, a doped heavy body positioned adjacent each source junction, the deepest portion of each said heavy body extending less deeply into said semiconductor substrate than said predetermined depth of said trenches, (e) a doped well surrounding each heavy body beneath the heavy body; and (f) p+ and n+ contacts disposed at the surface of the semiconductor substrate and arranged in alternation along the length of the contact area.

Preferred embodiments include one or more of the following features. The first and second dopants both comprise boron. The first energy is from about 150 to 200 keV. The first dosage is from about $1E15$ to $5E15$ cm⁻². The second energy is from about 20 to 40 keV. The second dosage is from about $1E14$ to $1E15$ cm⁻².

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In yet another aspect, the invention features a semiconductor die that includes (a) a plurality of DMOS transistor cells arranged in an array on a semiconductor substrate, each DMOS transistor cell including a gate-forming trench, each of said gate-forming trenches having a predetermined depth, the depth of all of the gate-forming trenches being substantially the same; and (b) surrounding the periphery of the array, a field termination structure that extends into the semiconductor substrate to a depth that is deeper than said predetermined depth of said gate-forming trenches.

Preferred embodiments include one or more of the following features. The first dopant comprises arsenic and the second dopant comprises phosphorus. The first energy is from about 80 to 120 keV. The first dosage is from about $5E15$ to $1E16$ cm⁻². The second energy is from about 40 to 70 keV. The second dosage is from about $1E15$ to $5E15$ cm⁻². The resulting depth of the source is from about 0.4 to 0.8 μ m the finished DMOS transistor.

The invention also features a method of making a heavy body structure for a trench DMOS transistor including (a) providing a semiconductor substrate; (b) implanting into a region of the substrate a first dopant at a first energy and dosage; and (c) subsequently implanting into said region a second dopant at a second energy and dosage, said second energy and dosage being relatively less than said first energy and dosage.

Preferred embodiments include one or more of the following features. The first and second dopants both comprise boron. The first energy is from about 150 to 200 keV. The first dosage is from about $1E15$ to $5E15$. The second energy is from about 20 to 40 keV. The second dosage is from about $1E14$ to $1E15$.

Additionally, the invention features a method of making a source for a trench DMOS transistor including (a) providing a semiconductor substrate; (b) implanting into a region of the substrate a first dopant at a first energy and dosage; and (c) subsequently implanting into the region a second dopant at a second energy and dosage, the second energy and dosage being relatively less than the first energy and dosage.

Preferred embodiments include one or more of the following features. The first dopant comprises arsenic and the second dopant comprises phosphorus. The first energy is from about 80 to 120 keV. The first dosage is from about $5E15$ to $1E16$. The second energy is from about 40 to 70 keV. The second dosage is from about $1E15$ to $5E15$. The resulting depth of the source is from about 0.4 to 0.8 μ m in the finished DMOS transistor.

In another aspect, the invention features a method of manufacturing a trench field effect transistor. The method includes (a) forming a field termination junction around the perimeter of a semiconductor substrate, (b) forming an epitaxial layer on the semiconductor substrate, (c) patterning and etching a plurality of trenches into the epitaxial layer; (d) depositing polysilicon to fill the trenches, (e) doping the polysilicon with a dopant of a first type, (f) patterning the substrate and implanting a dopant of a second, opposite type to form a plurality of wells interposed between adjacent trenches, (g)

patterning the substrate and implanting a dopant of the second type to form a plurality of second dopant type contact areas and a plurality of heavy bodies positioned above the wells, each heavy body having an abrupt junction with the corresponding well, (h) patterning the substrate and implanting a dopant of the first type to provide source regions and first dopant type contact areas; and (i) applying a dielectric to the surface of the

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semiconductor substrate and patterning the dielectric to expose electrical contact areas.

Other features and advantages of the invention will be apparent from the is following detailed description, and from the claims.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is a highly enlarged, schematic perspective cross-sectional view showing a portion of a cell array including a plurality of DMOS transistors according to one aspect of the invention. The source metal layer and a portion of the dielectric layer have been omitted to show the underlying layers. FIGS. 1a and 1b are side cross-sectional views of a single line of transistors from the array of FIG. 1, taken along lines A—A and B—B, respectively. In FIGS. 1a and 1b the source metal and dielectric layers are shown.

FIG. 2 is a highly enlarged schematic side cross-sectional view of a semiconductor die showing a portion of the cell array and the field termination.

FIG. 3 is a flow diagram showing the photo mask sequence of a preferred process for forming a trench DMOS transistor of FIG. 1.

FIGS. 4-4k are schematic side cross-sectional views showing the individual steps of the process diagrammed in FIG. 3. The figure numbers for the detailed views in FIGS. 4-4k are shown parenthetically under the corresponding diagram boxes in FIG. 3.

FIGS. 5-5b are spreading resistance profile graphs, reflecting the dopant concentration distribution at different regions of the transistor.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

A cell array 10, including a plurality of rows 12 of trench DMOS transistors, is shown in FIG. 1. Cell array 10 has an open cell configuration, i.e., trenches 14 run in only one direction, rather than forming a grid. Individual cells are formed by alternating n+ source contacts 16 and p+ contacts 18 in rows 20 that run parallel to and between trenches 14. The configuration of the regions of each row that have an n+ source contact are shown in cross-section in FIG. 1a, while the regions that have a p+ contact are shown in FIG. 1b.

As shown in FIGS. 1a and 1b, each trench DMOS transistor includes a doped n+ substrate (drain) layer 22, a more lightly doped n- epitaxial layer 24, and a gate electrode 28. Gate electrode 28 comprises a conductive polysilicon that fills a trench 14. A gate oxide 26 coats the walls of the trench and underlies the polysilicon. The top surface of the polysilicon is recessed from the surface 30 of the semiconductor substrate by a distance R (typically from about 0 to 0.4 μ m). N+ doped source regions 32a, 32b are positioned one on each side of the trench 14. A dielectric layer 35 covers the trench opening and the two source regions 32a, 32b. Extending between the source regions of adjacent cells is a p+ heavy body region 34 and, beneath it, a flat-bottomed p- well 36. In the areas of the cell array which have a n+ contact 16, a shallow n+ doped contact region extends between the n+ source regions. A source metal layer 38 covers the surface of the cell array.

The transistor shown in FIGS. 1a and 1b includes several features that enhance the ruggedness of the transistor and its resistance to avalanche breakdown degradation.

First, the depth of the p+ heavy body region 34 relative to the depths of the trench 14 and the flat bottom of the p- well

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is selected so that the peak electric field when voltage is applied to the transistor will be approximately halfway between adjacent trenches. The preferred relative depths of the p+ heavy body, the p- well and the trench are different for different device layouts. However, preferred relative depths can be readily determined empirically (by observing the location of peak electric field) or by finite element analysis.

Second, the bottom corners of the trench 14 are rounded (preferably, the top corners are also rounded; this feature is not shown). Corner rounding can be achieved using the process described in U.S. application Ser. No. 08/959,197, filed on Oct. 28, 1997, now U.S. Pat. No. 6,103,635. The rounded corners of the trench also tend to cause the peak electric field to be moved away from the trench corners and towards a central location between adjacent trenches.

Third, an abrupt junction at the interface between the p+ heavy body and the p- well causes the peak electric field to occur in that area of the interface. Avalanche multiplication initiates at the location of the peak electric field, thus steering hot carriers away from the sensitive gate oxide and channel regions. As a result, this structure improves reliability and avalanche ruggedness without sacrificing cell density as much as a deeper heavy body junction. This abrupt junction can be achieved by the double doping process that will be described below, or by other processes for forming abrupt junctions, many of which are known in the semiconductor field.

Lastly, referring to FIG. 2, the cell array is surrounded by a field termination junction 40 which increases the breakdown voltage of the device and draws avalanche current away from the cell array to the periphery of the die. Field termination junction 40 is a deep p+ well, preferably from about 1 to 3 μm deep at its deepest point, that is deeper than the p+ heavy body regions 34 in order to reduce the electric field caused by the junction curvature. A preferred process for making the above-described transistors is shown as a flow diagram in FIG. 3, and the individual steps are shown schematically in FIGS. 4-4k. It is noted that some steps that are conventional or do not require illustration are described below but not shown in FIGS. 4-4k. As indicated by the arrows in FIG. 3, and as will be discussed below, the order of the steps shown in FIGS. 4-4k can be varied. Moreover, some of the steps shown in FIGS. 4-4k are optional, as will be discussed.

A semiconductor substrate is initially provided. Preferably, the substrate is a N++ Si substrate, having a standard thickness, e.g., 500 μm , and a very low resistivity, e.g., 0.001 to 0.005 Ohm-cm. An epitaxial layer is deposited onto this substrate, as is well known, preferably to a thickness of from about 4 to 10 μm . Preferably the resistivity of the epitaxial layer is from about 0.1 to 3.0 Ohm-cm.

Next, the field termination junction 40 is formed by the steps shown in FIGS. 4-4c. In FIG. 4, an oxide layer is formed on the surface of the epitaxial layer. Preferably, the thickness of the oxide is from about 5 to 10 $\text{k}\text{\AA}$. Next, as shown in FIG. 4a, the oxide layer is patterned and etched to define a mask, and the p+ dopant is introduced to form the deep p+ well field termination. A suitable dopant is boron, implanted at an energy of from about 40 to 100 keV and a dose of $1\text{E}14$ (1×10^{14}) to $1\text{E}16$ cm^{-2} . As shown in FIG. 4b, the p+ dopant is then driven further into the substrate, e.g., by diffusion, and a field oxide layer is formed over the p+ junction. Preferably the oxide thickness is from about 4 to 10 $\text{k}\text{\AA}$. Finally, the oxide (FIG. 4) over the active area of the substrate (the area where the cell array will be formed) is

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patterned and removed by any suitable etching process, leaving only the field oxide in suitable areas. This leaves the substrate ready for the following steps that will form the cell array.

It is noted that, as an alternative to steps 4-4c, a suitable field termination structure can be formed using a ring-shaped trench which surrounds the periphery of the cell array and acts to lessen the electric field and increase the resistance to avalanche breakdown degradation. This trench field termination does not require a field oxide or deep p+ body junction to be effective. Consequently, it can be used to reduce the number of process steps. Using a trench ring (or multiple concentric trench rings) to form a field termination is described in, e.g., U.S. Pat. No. 5,430,324, the full disclosure of which is hereby incorporated herein by reference. Preferably, the trench would have substantially the same depth as the trenches in the cell array.

The cell array is formed by the steps shown in FIGS. 4d-4k. First, a plurality of trenches are patterned and etched into the epitaxial layer of the substrate (FIG. 4d). Preferably, as noted above, the trenches are formed using the process U.S. application Ser. No. 08/959,197, filed on Oct. 28, 1997, now U.S. Pat. No. 6,103,635, so that the upper and lower corners of each trench will be smoothly rounded. As shown in FIG. 1 and described above, the trenches are patterned to run in only one direction, defined as an open cell structure. After trench formation, a gate oxide layer is formed on the trench walls, as is well known in the semiconductor field. Preferably the gate oxide has a thickness of from about 100 to 800 \AA .

Next, as shown in FIG. 4e, polysilicon is deposited to fill the trench and cover the surface of the substrate, generally to a thickness of from about 1 to 2 μm depending on the trench width (shown by the dotted lines in FIG. 4e). This layer is then planarized by the nature of its thickness relative to the trench width, typically from about 2 to 5 $\text{k}\text{\AA}$ (indicated by solid lines in FIG. 4e). The polysilicon is then doped to n-type, e.g., by conventional POCl_3 doping or by phosphorus implant. The backside of the wafer need not be stripped (as is conventionally done prior to doping the polysilicon to enhance defect gettering) because any further doping of the highly doped substrate would be unlikely to result in any enhancement in defect gettering.

The polysilicon is then patterned with a photoresist mask and etched to remove it from the trench areas, as shown in FIG. 4f. A small recess between the top of the polysilicon in the trench and the substrate surface inherently results when the polysilicon is etched completely to remove all of the polysilicon from the substrate surface. The depth of this recess must be controlled so that it does not exceed the depth of the n+ source junction that will be formed in a later step. To reduce the need to carefully control this aspect of the process, a relatively deep n+ source junction is formed, as will be discussed below.

Then, as shown in FIG. 4g, the p- well is formed by implanting the dopant, e.g., a boron implant at an energy of 30 to 100 keV and a dosage of $1\text{E}13$ to $1\text{E}15$, and driving it in to a depth of from about 1 to 3 μm using conventional drive in techniques.

The next two steps (p+ heavy body formation) can be performed either before formation of the n+ source junction, or afterwards, as indicated by the arrows in FIG. 3. P+ heavy body formation and n+ source junction formation can be performed in either order because they are both resist-masked steps and because there is no diffusion step in between. This advantageously allows significant process

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flexibility. The p+ heavy body formation steps will be described below as being performed prior to source formation; it will be understood that n+ source formation could be performed first simply by changing the order of the steps discussed below.

First, a mask is formed over the areas that will not be doped to p+, as shown in FIG. 4h. (It is noted that this masking step is not required if the p+ heavy body is formed later, after the dielectric layer has been applied and patterned for contact holes. (see FIG. 4k, below) so that the dielectric itself provides a mask.) As discussed above, it is preferred that the junction at the interface between the p- well and the p+ heavy body be abrupt. To accomplish this, a double implant of dopant (e.g., boron) is performed. For example, a preferred double implant is a first boron implant at an energy of 150 to 200 keV and a dose of $1\text{E}15$ to $5\text{E}15\text{ cm}^{-2}$, and a second boron implant at an energy of 20 to 40 keV and a dose of $1\text{E}14$ to $1\text{E}15\text{ cm}^{-2}$. The high energy first implant brings the p+ heavy body as deep as possible into the substrate, so that it will not compensate the n+ source junction to be introduced later. The second, lower energy/lower dose implant extends the p+ heavy body from the deep region formed during the first implant up to the substrate surface to provide the p+ contact 18. The resulting p+ heavy body junction is preferably about 0.4 to 1 μm deep at this stage of the process (final junction depth after drive-in is preferably about 0.5 to 1.5 μm deep), and includes a region of high dopant concentration near the interface with the p-well, and a region of relatively low dopant concentration at the contact surface of the p+ heavy body. A preferred concentration distribution is shown in FIG. 5.

It will be appreciated by those skilled in the art that the abrupt junction can be formed in many other ways, e.g., by diffused dopants, by using a continuous dopant source at the surface or by using atoms that diffuse slowly.

After the formation of the p+ heavy body, a conventional resist strip process is performed to remove the mask, and a new mask is patterned to prepare the substrate for the formation of the n+ source junction. This mask is a n-blocking mask and is patterned to cover the areas of the substrate surface which are to provide p+ contacts 18 (FIGS. 1 and 1b), as shown in FIG. 4i. This results in the formation of alternating p+ and n+ contacts after n-type doping (see lines A—A and B—B and cross-sectional views A—A and B—B in FIG. 4l, which correspond to FIGS. 1a and 1b).

The n+ source regions and n+ contact are then formed using a double implant. For example, a preferred double implant process is a first implant of arsenic at an energy of 80 to 120 keV and a dose of $5\text{E}15$ to $1\text{E}16\text{ cm}^{-2}$ followed by a second implant of phosphorus at an energy of 40 to 70 keV and a dose of $1\text{E}15$ to $5\text{E}15\text{ cm}^{-2}$. The phosphorus implant forms a relatively deep n+ source junction, which allows more process flexibility in the depth of the polysilicon recess, as discussed above. Phosphorus ions will penetrate deeper into the substrate during implant and also during later diffusion steps. Advantageously, the n+ source regions will have a depth of about 0.4 to 0.8 μm after diffusion. The arsenic implant extends the n+ source to the substrate surface, and also forms the n+ contacts 16 (see FIGS. 1 and 1a) by compensating (converting) the p-type surface of the p+ heavy body to n-type in the desired contact area. The preferred sheet resistance profiles for the n+ source along the edge of the trench, and the n+ contact are shown in FIGS. 5a and 5b, respectively.

Thus, the alternating p+ and n+ contacts 18, 16, shown in FIG. 1 are formed by patterning the substrate with appro-

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prate masks and doping with the first p+ implant and the second n+ implant, respectively, as described above. This manner of forming the alternating contacts advantageously allows an open cell array having a smaller cell pitch than is typical for such arrays and thus a higher cell density and lower $R_{ds, on}$.

Next, a conventional n+ drive is performed to activate the dopants. A short cycle is used, preferably 10 min at 900° C., so that activation occurs without excessive diffusion.

A dielectric material, e.g., borophosphate silicate glass (BPSG), is then deposited over the entire substrate surface and flowed in a conventional manner (FIG. 4j), after which the dielectric is patterned and etched (FIG. 4k) to define electrical contact openings over the n+ and p+ contacts 16, 18.

As noted above, the p+ heavy body implant steps can be performed at this point, if desired (rather than prior to n+ source formation), eliminating the need for a mask and thus reducing cost and process time.

Next, the dielectric is reflowed in an inert gas, e.g., a nitrogen purge. If the p+ body has been implanted immediately prior, this step is required to activate the p+ dopant. If the p+ body was implanted earlier, prior to the n+ drive, this step can be omitted if the dielectric surface is sufficiently smooth-edged around the contact openings.

The cell array is then completed by conventional metalization, passivation deposition and alloy steps, as is well known in the semiconductor field.

Other embodiments are within the claims. For example, while the description above is of an n-channel transistor, the processes of the invention could also be used to form a p-channel transistor. To accomplish this, "p" and "n" would simply be reversed in the above description, i.e., where "p" doping is specified above the region would be "n" doped instead, and vice versa.

What is claimed is:

1. A method of manufacturing a trench transistor comprising:
 - providing a semiconductor substrate having dopants of a first conductivity type;
 - forming a plurality of trenches extending to a first depth into the semiconductor substrate;
 - lining each of the plurality of trenches with a gate dielectric material;
 - substantially filling each dielectric-lined trench with conductive material;
 - forming a doped well in the substrate to a second depth that is less than said first depth of the plurality of trenches, the doped well having dopants of a second conductivity type opposite to said first conductivity type;
 - forming a heavy body extending inside the doped well to a third depth that is less than said second depth of said doped well, the heavy body having dopants of the second conductivity type and forming an abrupt junction with the well; and
 - forming a source region inside the well, the source region having dopants of the first conductivity types.
2. The method of claim 1 wherein the step of forming a doped well forms the well with a substantially flat bottom.
3. The method of claim 1 further comprising forming a deep doped region having dopants of the second conductivity type, the deep doped region extending into the substrate to a fourth depth that is deeper than said first depth of the trench.

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4. The method of claim 3 wherein the step of forming a deep doped region forms a PN junction diode with the substrate that helps improve a breakdown voltage of the transistor.

5. The method of claim 3 wherein the deep doped region forms a termination structure around the periphery of the substrate.

6. The method of claim 1 wherein the step of substantially filling each dielectric-lined trench leaves a recess at an upper portion of each trench.

7. The method of claim 6 further comprising filling the recess at the upper portion of each trench with dielectric material.

8. The method of claim 1 wherein the step of forming the heavy body comprises a double implant process.

9. The method of claim 8 wherein the double implant process comprises:

a first implant of dopants of the first conductivity type, at a first energy level and a first dosage to form a first doped portion of the heavy body; and

a second implant of dopants of the first conductivity type, at a second energy level and a second dosage to form a second doped portion of the heavy body.

10. The method of claim 9 wherein the first implant occurs at approximately the third depth.

11. The method of claim 9 wherein the first energy level is higher than the second energy level.

12. The method of claim 11 wherein the first dosage is higher than the second dosage.

13. The method of claim 1 wherein the step of forming the heavy body comprises a process of diffusing dopants of the second conductivity type.

14. The method of claim 1 wherein the step of forming the heavy body comprises using a continuous dopant source at the surface of the semiconductor substrate.

15. The method of claim 1 wherein the step of forming a plurality of trenches comprises patterning and etching the plurality of trenches that extend in parallel along a longitudinal axis.

16. The method of claim 15 further comprising forming a contact area on the surface of the substrate between adjacent trenches.

17. The method of claim 16 wherein the step of forming the contact area comprises forming alternating source contact regions and heavy body contact regions.

18. The method of claim 16 wherein the step of forming the contact area comprises forming a ladder-shaped source contact region surrounding heavy body contact regions.

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19. The method claim 18 wherein the step of forming the ladder-shaped source contact region surrounding heavy body contact regions, comprises:

forming a source blocking mask on the surface of the semiconductor substrate patterned to cover the heavy body contact regions; and

implanting dopants of the first conductivity type to form the ladder-shaped source contact region.

20. The method of claim 18 wherein the step of forming the ladder-shaped source contact region surrounding heavy body contact regions, comprises forming a dielectric layer on the surface of the semiconductor substrate patterned to expose the heavy body contact regions.

21. A method of manufacturing a trench field effect transistor on a semiconductor substrate having dopants of a first conductivity type, the method comprising:

etching a plurality of trenches into the semiconductor substrate to a first depth;

lining the plurality of trenches with dielectric layer;

substantially filling the dielectric-lined plurality of trenches with conductive material;

forming a well between adjacent trenches to a second depth that is shallower than the first depth, the well having dopants of second conductivity type opposite to the first conductivity type;

forming a heavy body inside the well to a third depth that is shallower than the second depth, the heavy body having dopants of the second conductivity type; and

forming a source region inside the well and adjacent to trenches, the source region having dopants of the first conductivity type,

wherein, the step of forming a heavy body employs a process to form an abrupt junction between the heavy body and the well at approximately the third depth.

22. The method of claim 21 further comprising adjusting a location of the abrupt junction relative to the depth of the well so that a transistor breakdown current is spaced away from the trench in the semiconductor.

23. The method of claim 21 further comprising forming a deep doped region having dopants of the second conductivity type, the deep doped region extending into the substrate to a fourth depth that is deeper than said first depth of the trench.

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